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USER'S MANUAL FOR MAVPAT, A MAVART3D TO PATRAN TRANSLATOR

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Centre de Recherches pour la Défense Atlantique

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Abstract

This communication describes how to use the computer program MAVPAT, Version 1.0, developed at Defence Research Establishment Atlantic (DREA) to translate MAVART3D analysis results files to a form compatible with the finite element modelling program PATRAN. MAVART3D is a computer program used for finite element analysis of piezoelectric sonar transducers. Once read by PATRAN, the translated MAVART3D analysis results can be displayed graphically, and superimposed on images of the finite element model. This communication shows how to configure the PATRAN software so that finite element model generation, MAVART3D analysis, data translation, and display of results can all be done within the PATRAN environment. The integrated operation of PATRAN, PATMAV, MAVART3D, and MAVPAT is illustrated with the worked example of the modal analysis of the shell of a barrel stave projector. The example also shows how PATRAN Command Language can be used in the parametric design of a sonar transducer.

Résumé

La présente communication décrit le mode d'utilisation de la version 1.0 du programme informatique MAVPAT, écrit au Centre de recherches pour la défense Atlantique (CRDA), pour convertir les fichiers de résultats d'analyse du MAVART3D en une forme compatible avec le programme PATRAN de modélisation par éléments finis. MAVART3D est un programme informatique d'analyse par éléments finis de transducteurs de sonars piézo-électriques. Une fois lus par PATRAN, les résultats convertis de l'analyse effectuée par MAVART3D peuvent être affichés graphiquement et superposés à des images du modèles par éléments finis. La presente communication montre comment configurer le logiciel PATRAN pour que la génération de modèles à éléments finis, l'analyse par le programme MAVART3D, la conversion des données et l'affichage des résultats puissent tous être effectués dans l'environnement PATRAN. L'exploitation intégrée de PATRAN, PATMAV, MAVART3D et MAVPAT est illustrée au moyen de l'example d'analyse modale de l'enveloppe d'un projecteur en douve de baril. L'exemple montre aussi comment le LANGAGE DE COMMANDE PATRAN (PCL) peut être utilisé dans la conception paramétrique d'un transducteur de sonar.

Contents

1 Introduction

The Transducer Group of the Defence Research Establishment Atlantic (DREA) designs transducers such as hydrophones and underwater sound projectors in support of the Establishment's research programs in underwater acoustics. One of the most important design tools available to the DREA Transducer Group is finite element analysis. Special purpose finite element analysis codes, such as MAVART3D[1, 2], are used. MAVART3D is distinguished from other finite element codes for mechanical engineering in that it can analyse the deformations and vibrations of piezoelectric materials.

Because MAVART3D is strictly for analysis, and has no graphical display capabilities, a requirement exists for computer software to display the results of MAVART3D finite element analysis, and superimpose these results on images of the finite element models. The PATRAN[3] model generation software, from PDA Engineering, is used at DREA for creation of finite element models for MAVART3D and other analysis codes. PATRAN also has extensive support for the display of finite element analysis results, so it is the obvious choice for MAVART3D results display. Model output files from PATRAN are translated by the "forward translator", PATMAV[4], to a form ready for analysis by MAVART3D. After MAVART3D analysis is complete, the results must be translated to a form that is readable back into PATRAN. The program MAVPAT, described in this communication, was written to do this "reverse translation". The combination of PATRAN, PATMAV, MAVART3D, and MAVPAT permit model creation, analysis, and results display, all within one software environment that will be useful for the design of sonar transducers.

1.1 Organization of the Manual

This document is organized into 5 sections followed by the list of references and appendicies. Section 1 provides an introduction and historical overview of the MAVPAT software development. Section 2 describes the software configuration for consecutive operation of the PATRAN, PATMAV, MAVART3D, and MAVPAT software. Section 3 describes the configuration for concurrent operation where PATMAV, MAVART3D, and MAVPAT are run from within the PATRAN environment. Section 4 presents an example illustrating the use of the PATRAN, PATMAV, MAVART3D, and MAVPAT software, and models a transducer component with PATRAN Command Language. Section 5 is a summary containing proposals for future development of the MAVPAT software. Appendix A lists the command procedures used to invoke file translation from within PATRAN. Appendix B describes the format of the results files produced by MAVPAT.

1.2 PATRAN, PATMAV, MAVART3D, and MAVPAT

PATRAN PLUS Version 2.5[3], a product of PDA Engineering, Costa Mesa, California, is an integrated set of computer programs for the creation of finite element models for mechanical engineering. It also provides extensive support for the display of the results of finite element analysis. The models created with PATRAN are written to a file called the PATRAN Neutral file. The program PATMAV, Version 1.0[4], was developed at Defence Research Establishment

Atlantic (DREA) to translate PATRAN Neutral files to a form ready for analysis by the program MAVART3D. MAVART3D Version 1.0[1, 2] is a finite element analysis program developed under contract to DREA by Acres International Ltd., Niagara Falls, Ontario, during the period 1990-91. MAVART3D is based on the program MAVART, developed for DREA by Canadian industry in a series of research contracts during the period 1975-1988. The name MAVART is an acronym for Model for the Analysis of the Vibrations and Acoustic Radiation of Transducers. The purpose of MAVART is to analyze the performance of axisymmetric piezoelectric sonar transducers. The program MAVART3D extends the capabilities of MAVART to the analysis of transducers that have no symmetry axes[1].

MAVPAT, Version 1.0, was developed at DREA in 1991, to translate MAVART3D analysis results files to a form ready for display by PATRAN. MAVPAT, like PATMAV and MAVART3D, is written in Fortran-77 and has been developed for use on Digital Equipment Corp. VAX computers using the VMS operating system. MAVPAT requires little user input, so that most of this communication concerns file specifications and system configuration. Also, an example is presented in Section 4 showing how PATRAN, PATMAV, and MAVART3D can be used to create and analyze a finite element model of a transducer, and how MAVPAT and PATRAN can be used to display the results. The model is built using PATRAN Command Language (PCL)[5]. The example illustrates a technique for model generation, called *parametric modelling*, where the model generation is controlled by a small number of design parameters. This modelling method is ideally suited for optimizing the performance of a transducer by varying some of the design parameters. The example shows how model preparation, Neutral file translation, MAVART3D finite element analysis, and display of results can all be accomplished within a single PATRAN session.

2 Software Configuration for Consecutive Operation

The following site specific VMS definitions permit the programs described in this section to be invoked simply by typing their names.

```
$ PATRAN:== @$1$dus2:[softpacs.patran]patran_run
$ PATMAV:== run dreapacs:[mavart]patmav.exe
$ MAVART3D:== run dreapacs:[mavart.mavart3d]mavart3d.exe
$ MAVPAT:== run dreapacs:[mavart]mavpat.exe
$ POSTSCRIPT:== run $1$dus2:[softpacs.patran.patran25.hardcopy]postscript.exe
```

Fig. 1 illustrates the relationships between the programs and some of the data files that make up the PATRAN-PATMAV-MAVART3D-MAVPAT software environment when they are used consecutively, i.e., each piece of software is run to task completion before the next program is invoked. In Fig. 1 the computer programs are indicated by circles; the data files by rectangles. The arrows indicate data-flow directions; the switches indicate optional data-flow paths. PATRAN reads and writes to over 20 different data files during its operations, Fig. 1 shows only the most commonly used ones.

[1]Acoustic radiation is not yet modelled by MAVART3D, it will be included in Version 2.0 of the software scheduled for delivery in 1993.

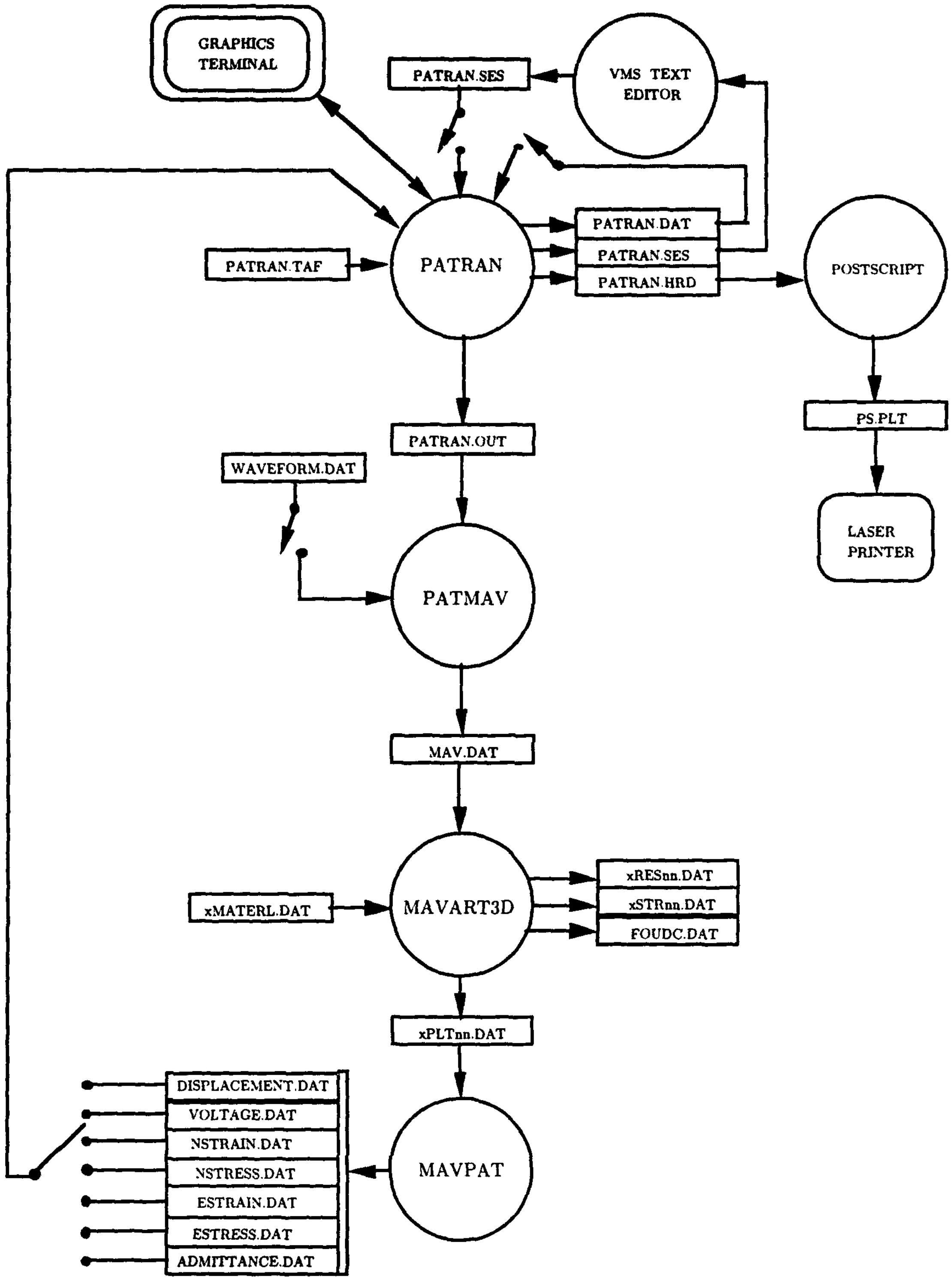

Figure 1: *PATRAN-MAVART3D flowchart for consecutive operation.*

In Fig. 1 PATRAN is shown being controlled from a graphics terminal. Problems with the graphics, e.g., colour mapping, or image size, can be due to incorrect descriptions of terminal attributes. These are stored in the terminal attributes file PATRAN.TAF. The system manager can edit this file to modify the terminal description as required.

All user input to PATRAN is copied to the session file PATRAN.SES which, as indicated in Fig. 1, can be modified by a text editor and used to control a new PATRAN session. This capability is useful. It permits the user to experiment freely with different PATRAN model building techniques, knowing that if mistakes are made, the session can be reconstructed by exiting PATRAN; the unwanted modelling commands can be edited out of the session file, and then the edited session file can be used to reconstruct the model. Also, the session file can be run in single step mode for debugging purposes.

At the end of a PATRAN session, PATRAN generates the file PATRAN.DAT which contains, in addition to the model geometry, the graphics parameters for such items as colours, windows, viewpoints, rotations, etc. This file can be read at startup of a subsequent PATRAN session to quickly restore a model for further work, without having to reprocess all the commands in the previous session file.

As indicated in Fig. 1, hardcopy output of PATRAN graphics are written to the file PATRAN.HRD. This file can be translated into Postscript format using the PATRAN translator program POSTSCRIPT[3]. The translated file, given the name PS.PLT, can be printed on a Postscript compatible colour or black and white printer.

The PATRAN Neutral file, containing the finite element model data, is PATRAN.OUT. It is called Neutral because the data it contains is the same regardless of computer system or graphics terminal used in its creation. This is in contrast to the file PATRAN.DAT, which is sensitive to the type of graphics terminal used. After the PATRAN session is terminated, the PATRAN-to-MAVART3D translator, PATMAV[4], can be run. The highest numbered version of the Neutral file PATRAN.OUT is read and translated to MAVART3D compatible form by PATMAV. The user is prompted for data needed by MAVART3D that cannot be obtained from the Neutral file. The only other file accessed by PATMAV is indicated in Fig. 1 as WAVEFORM.DAT, which describes the waveform of a transient excitation, an option used only if a MAVART3D "TRANsient" analysis is selected in PATMAV. PATMAV's output file, MAV.DAT, is ready for use as the input data file for MAVART3D.

The user must provide MAVART3D with the input data file name (e.g., MAV.DAT). The user must also input a single character (substituted for the dummy prefix" x" in following file names) which is used to identify an optional material data file, xMATERL.DAT, and which forms an identifying prefix to label the output files. MAVART3D produces a number of output files[1], some of which are shown in Fig. 1. Only the plot file with the name xPLTnn.DAT is used by MAVPAT. The dummy suffix "nn" is a version number built into the file name. This naming convention was added to the most recent versions of MAVART and MAVART3D to facilitate portability to other computer operating systems. The MAVART3D plot file is an unformatted file, with a file header containing all MAVART3D data array dimensions[2].

[2]The array dimensions are stored in the file DREAPACS:[MAVART.MAVART3D]M3DSIZ.INC, used in the compilation of MAVART3D.

2.0.1 MAVPAT User Input

The program MAVPAT prompts the user for the name of the MAVART3D plot file, e.g., xPLTnn.DAT. MAVPAT checks for the existence of the selected plot file and prompts for a new selection if the selected file does not exist. MAVPAT reads the plot file header to obtain the dimensions of the plot file's data records. MAVPAT terminates with a fatal error message if it has been compiled with insufficient data array dimensions. The message will indicate which array dimension needs to be increased. A carriage return supplied in response to the query for the plot file name terminates the program. The only other user input required by MAVPAT, is the number of phases (animation frames) desired for animation of displacement and voltage results from MAVART3D DRIV analysis[1] described in Section 2.0.5 below.

2.0.2 MAVPAT Output Files

MAVPAT rewrites the data in xPLTnn.DAT into a series of files in the format of PATRAN results files[3]. The number of files written depends on the MAVART3D analysis type. MAVPAT utilizes the VMS naming convention for its output files, i.e., they are identified by version numbers. Table 1 gives the names and purposes of the data files produced by MAVPAT for different MAVART3D analysis types.

The output files generated by MAVPAT are formatted (ASCII) files[3] that can be read by ordinary text editors. PATRAN can read three types of results files: nodal, element, and X-Y data. Nodal results files contain results computed at nodes, element results files contain results computed at element centroids, and X-Y data files contain two columns, the independent and dependent variables, respectively, e.g., frequency and admittance. MAVPAT produces all three types of results file as indicated in Table 1. The generic format of these files is described in [3]. Specific formats for the files listed in Table 1 are described in Appendix B.

[3]PATRAN can also read unformatted (binary) results files, but to facilitate portability of results files across computer systems, only formatted files are produced by MAVPAT.

Table 1: *MAVPAT output files resulting from MAVART3D analysis.*

FILE NAME	TYPE	FILE CONTENTS	ANALYSIS TYPE
DISPLACEMENT.DAT	nodal	nodal displacements	STAT, EIGE, CAPA, DRIV
VOLTAGE.DAT	nodal	voltage at PIEZO nodes	STAT, EIGE, CAPA, DRIV
NSTRAIN.DAT	nodal	strain at corner nodes	STAT, CAPA, DRIV
NSTRESS.DAT	nodal	stress at corner nodes	STAT, CAPA, DRIV
ESTRAIN.DAT	element	strain at element centroids	STAT, CAPA, DRIV
ESTRESS.DAT	element	stress at element centroids	STAT, CAPA, DRIV
ADMITTANCE.DAT	X-Y	frequency sweep results	CAPA, DRIV

2.0.3 Displaying Results Files with PATRAN

The PATRAN software provides a number of ways to present finite element analysis results graphically. The displacements, voltages, stresses, strains, electric fields, and electric displacements can be visualized superimposed on images of the original model, using a variety of plotting techniques including vector and tensor plots, and colour and line contour plots.

To display analysis results with PATRAN, the model's PHASE 2 data (element data) must be in PATRAN's current ACTIVE SET[3]. If the model data are not already present, there are several ways to load a previously generated model. The `GO` command can be issued at PATRAN startup to retrieve the file PATRAN.DAT from the previous session. PATRAN could also be instructed to read in the model's Neutral File, using the `INTERFACE, NEUTRAL, INPUT MODEL` menu selections. If these two files are not available, it is also possible to rebuild the model using a copy of the model's session file. It is usually necessary to edit the session file, e.g., removing the final `STOP` command. To save time, the `SET, GRAPHICS, OFF` command can be added at the beginning of the session file to suppress plotting of all model generation steps. Then start PATRAN, instructing it with the `SES` command to start with the edited session file, or load the session file with the `READFILE` command. When the model is complete, graphics display can be enabled using the `SET, GRAPHICS, ON` command.

At this point, with the model loaded into PATRAN, there are a number of ways to instruct PATRAN to load results data depending on the type of data (nodal, element, or X-Y), and the type of results display required. A full description of all results display techniques is beyond the scope of this communication, instead, see Chapter 27 of [3]. Section 4.1 presents an example of the commands to select one type of results display.

2.0.4 Modal Analysis Results

The mode shape results from a MAVART3D EIGE analysis are written to a sequence of files xPLTnn.DAT, with one plot file created for each resonance frequency found. Thus MAVPAT will have to be run on each file xPLTnn.DAT in turn in order for PATRAN to be able to display the mode shapes corresponding to all the eigenfrequencies. The mode number and resonance frequency as found by MAVART3D are passed by MAVPAT to the file DISPLACMENT.DAT, and unless instructed otherwise with the `SET, LABD, OFF` command. PATRAN will include these numbers as part of the title of deformed geometry plots. Animations of real valued displacement results from EIGE or CAPA analysis can be generated with the `RESULTS, DISPLACEMENT, ANIMATE` commands.

2.0.5 Animation of DRIV Results

For MAVART3D analysis type DRIV, the solutions (displacements and voltages at nodes) are complex-valued[4]. PATRAN cannot interpret complex displacements directly, so these cases are handled by MAVPAT differently from STAT, EIGE, and CAPA results, which are real valued. When MAVPAT detects that a DRIV analysis has been completed, it prompts for the

[4]MAVART3D stress and strain results are real-valued magnitudes only.

number of output phases. The displacements and voltages of the model at the selected number of instants during one drive cycle are computed and written to a set of DISPLACEMENT.DAT and VOLTAGE.DAT files, one for each phase value. When these are later all read into PATRAN using e.g., the **RUN, ANIMATE** command, it is possible to animate the complex-valued DRIV results. Different parts of the model can be shown moving with different relative phases, something that would not be possible with purely real displacement data. This type of motion is typical of materials that have internal damping.

2.0.6 Plotting Frequency Sweep Results

PATRAN also has a facility for making X-Y plots of data using its P/PLOT module. MAVART3D frequency sweep results[1] such as admittance and impedance, are written by MAVPAT to the file ADMITTANCE.DAT, described in Appendix B, Table 10. This file can be read by the PATRAN P/PLOT module and be used to plot these results versus frequency. When a frequency sweep is done in a MAVART3D CAPA or DRIV analysis, a series of sequentially numbered plot files xPLTnn.DAT are created. The lowest numbered file (typically nn = 01) will contain the results from the first frequency in the sweep. The next file in the series (typically nn = 02) will contain the results of the next frequency in the sweep concatenated with the results of the previous plot file, and so on. Typically P/PLOT should be instructed to read and display the plot file with the highest value for "nn", since that file contains the frequency sweep results for all frequencies in the sweep. The plot files with lower numbers are also valuable, they contain, e.g., the displacement, stress, strain and directivity results for each frequency.

3 Software Configuration for Concurrent Operation

The programs PATRAN, PATMAV, MAVART3D, and MAVPAT can be run in a concurrent mode, in which all user input to PATMAV, MAVART3D, and MAVPAT, is entered from within the PATRAN environment. This software configuration is depicted in Fig. 2. In order for PATMAV, MAVART3D, and MAVPAT to be accessible from PATRAN it is necessary for the file PATRAN.IFC, indicated in Fig. 2, to be modified by the system manager, so that the first three lines of the file[5] are as follows:

```
MAVART3D
@dreapacs:[mavart]patmav.com
@dreapacs:[mavart]mavpat.com
```

The first line provides the name MAVART3D to the PATRAN **INTERFACE** command menu to be used as a label. The following two lines specify command procedures that are invoked when the **TO MAVART3D**, and **FROM MAVART3D** options in the PATRAN **INTERFACE** menu are selected. The Digital Command Language (DCL) procedures PATMAV.COM and MAVPAT.COM are listed in Appendix A.

[5]These lines are site specific. Putting them at the top of the file results in MAVART3D being the second pick in the PATRAN interface menu, with Neutral file creation being the default first menu item.

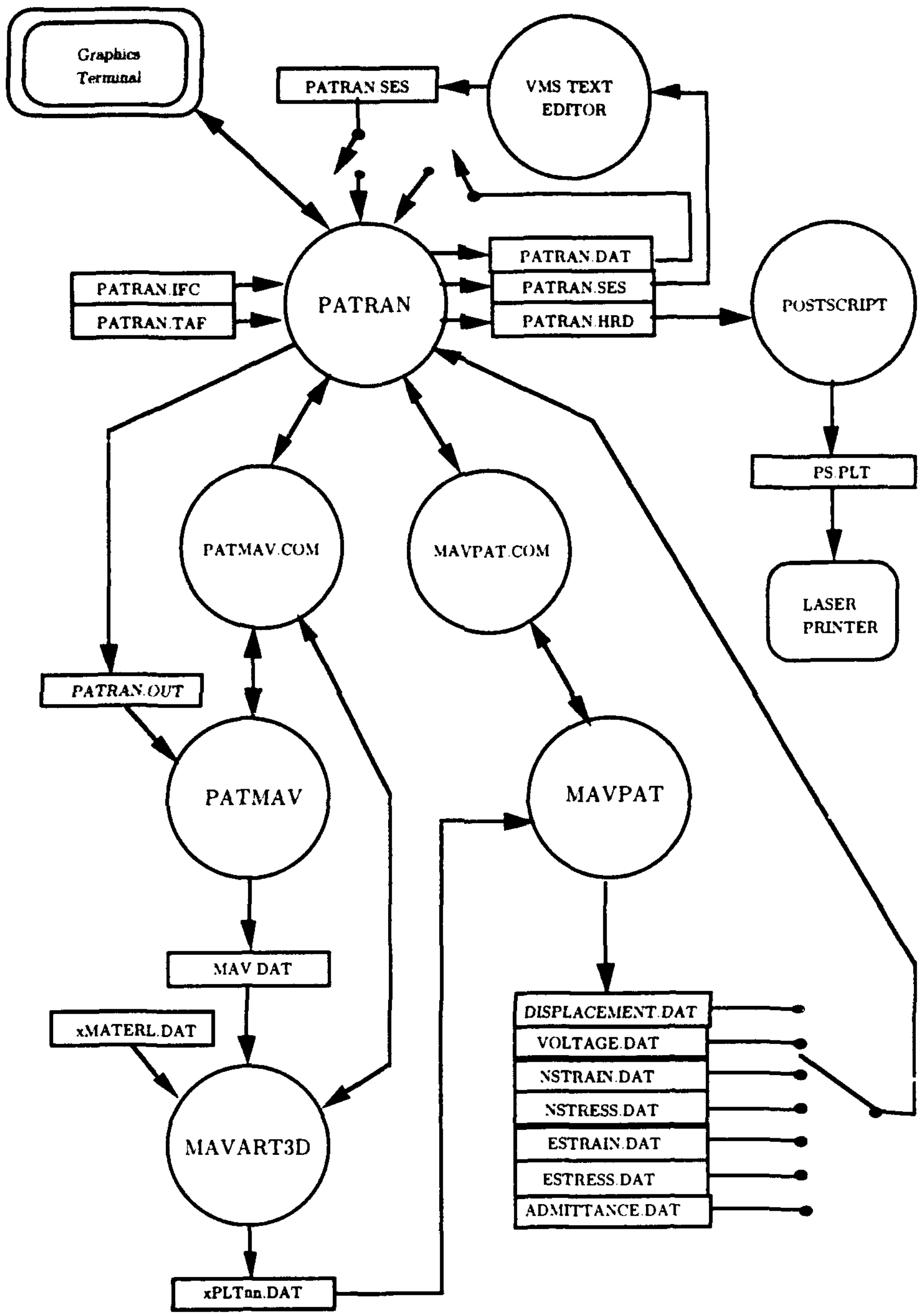

Figure 2: *PATRAN-MAVART3D flowchart for concurrent operation.*

The command procedure PATMAV.COM indicated in Fig. 2 runs the program PATMAV using data input from the terminal, followed by a submission of the MAVART3D job to a batch queue, typically one intended for large jobs. Control is then returned to PATRAN so that the user can continue working with PATRAN, while MAVART3D runs in the queue. The user is informed by a message printed to the terminal when the MAVART3D analysis is finished. At that point the `FROM MAVART3D` option of the PATRAN `INTERFACE` command can be selected. This will invoke the command procedure MAVPAT.COM which runs the program MAVPAT using data input from the terminal. Once MAVPAT translation is complete, control is returned to PATRAN, and the PATRAN `RESULTS` command can be selected to display the analysis results using the files created by MAVPAT, and listed in Table 1.

4 Example - Modal Analysis of Barrel Stave Shell

In this section, an example is presented that illustrates the use of PATRAN, PATMAV, MAVART3D, and MAVPAT. The example uses PCL, which is a programming language that supports PATRAN. PCL is useful for doing parametric design studies of transducers where numerous models must be constructed with different model parameters.

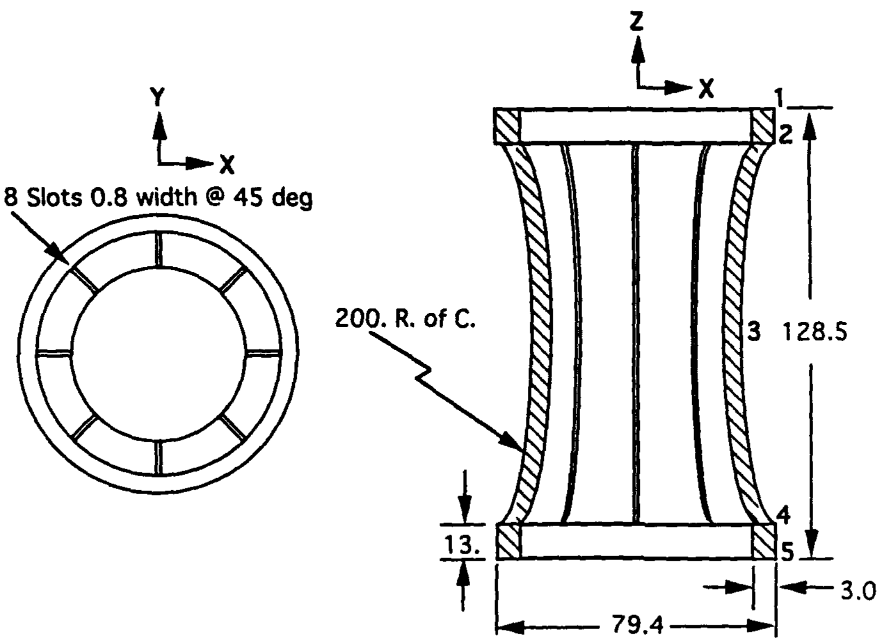

Figure 3: *Barrel Stave Projector Shell, dimensions in mm, not to scale.*

Fig. 3 is a sketch of an aluminum one-piece shell for a barrel stave projector. The purpose of the shell is to mechanically transform the axial motion produced by a piezoelectric stack (not shown here) to radial motion, with a transformer ratio of approximately 1:2. The shell has 8 slots, which are essential to its purpose. Without the slots, the shell's hoop stiffness

would be too high and the resultant transformer ratio would be uselessly small. Jones[6] used the axisymmetric finite element program MAVART[7, 8] to make preliminary designs of the shell by modelling the effect of the slots as a decrease in the tangential component of stiffness. The required modification to the material properties had to be determined experimentally, by building projectors, measuring their in-air admittance, and comparing this to the MAVART predictions. With the introduction of MAVART3D, it is now possible to analyze the in-air performance of the complete projector, with slots, using just handbook values for the material properties. To keep the example simple, a modal analysis of only the shell will be performed to predict the eigenfrequencies and mode shapes in vacuum.

To take advantage of PATRAN's capability of parametric modelling, the dimensions required to specify the model are stored in PCL variables in a session file. Therefore, the modelling process begins with examination of a drawing like Fig. 3 and a determination of what dimensions are both necessary and sufficient to completely define the model geometry. All other dimensions are derived from these by defining functional relationships in PCL.

The session file can be written entirely with a text editor, but it is often efficient to create a first draft of the session file interactively, with PATRAN, and later, add the PCL commands to the session file with an editor.

Table 2 contains a PATRAN session file that has been edited and annotated, and, when processed by PATRAN, will generate a finite element model of a barrel stave shell suitable for a modal analysis. The line numbers in the left-most column and the comments in the right-most column are not present in the session file, they are for reference only. Only essential commands are shown in Table 2, some preliminary commands have been deleted, and other commands to enhance the graphics, such as setting window size and view-point, etc., would normally also be used.

Line 1 of Table 2 is a comment line, these may be inserted anywhere in a PATRAN session file and begin with the $ symbol. Comments may also be inserted as in Line 2 where the dimensions are noted. Any consistent system of units can be used in creating PATRAN models. Line 2 defines the smallest non-zero distance.

The `PMAT` (Properties of Materials) command in Line 3, assigns a material identifier (mid) = 1, and defines the isotropy, stiffness, Poisson ratio, and density of the shell material. These are properties typical of the Aluminum alloy 6061-T6.

The first PCL command in the session is Line 4. PCL commands begin with an exclamation mark, and can be mixed throughout the session file's regular PATRAN commands. Lines 4-6 allocate storage for the PCL variables. Lines 7-14 specify values for the essential PCL variables. These are the data from which the entire model is generated. Lines 16-20 define derived variables in terms of the essential variables. When a PCL variable or expression is to be referenced by a PATRAN command, it is enclosed by backquotes as in Line 22.

Lines 22-27 define Grids, which are construction points used to aid in the construction of lines. The Grid points numbered 1-5 are indicated in Fig 3. The Grids numbered 6-10 are made by translating Grids 1-5 a distance equal to the thickness of the shell, in Line 27. Lines 28-35 create straight lines and circular arcs that define the cross-sectional shape of the shell.

Table 2: Session file for Shell Model

Line	PATRAN and PCL Commands	Comment
1	`$ MODAL ANALYSIS BARREL STAVE SHELL`	a PATRAN comment
2	`SET,TOLERANCE,1.0E-5  /* meters */`	smallest distance
3	`PMAT,1,ISO,6.9E10,,.33,2700`	material properties
4	`! GLOBAL REAL Radius,z0,z1,w,s,d1`	essential variables
5	`! GLOBAL INTEGER nstave`	
6	`! GLOBAL REAL r0,r1,z,x,staveangle,slotangle`	derived variables
7	`! nstave = 8`	number of staves
8	`! Radius = 0.2`	radius of curvature
9	`! z0 = 0.1285`	total height
10	`! z1 = 0.0130`	height of flanges
11	`! d0 = 0.0665`	o.d. at mid-point
12	`! d1 = 0.0794`	o.d. of top (or bottom)
13	`! w = 3.0E-3`	wall thickness
14	`! s = 8.0E-4`	slot width
15	`$ Next compute derived dimensions`	
16	`! r0 =0.5*d0`	radius at mid point
17	`! z = 0.5*(z0-2.0*z1)`	half height of slot
18	`! x = sqrt(Radius*Radius-z*z)`	c. of curvature to shell
19	`! slotangle = 0.5*s*180.0/(r0*3.1415926)`	half angular slot width
20	`! staveangle = 360.0/nstave-2.0*slotangle`	angular stave width
21	`$ Main body of PATRAN commands start`	
22	`GRID,1,,‘r0+Radius-x‘, 0.0,‘z0/2.0‘`	define grid points
23	`GRID,2,,‘r0+Radius-x‘, 0.0, ‘z‘`	top of slot
24	`GRID,3,,‘r0‘, 0.0, 0.0`	shell mid-point
25	`GRID,4,,X2, 0.0, ‘-z‘`	bottom of slot
26	`GRID,5,,X2, 0.0, ‘-z0/2.0‘`	bottom of shell
27	`GRID,6T10,TRANS,‘-w‘/0.0/0.0,1T5`	make grids on inside
28	`LINE,1,2GRID,,1,2`	define lines
29	`LINE,2,ARC3,,2/3/4`	
30	`LINE,3,2GRID,,4,5`	
31	`LINE,4T6,TRANSLATE,‘-w‘/0.0/0.0,1T3`	
32	`LINE,7,2GRID,,1,6`	
33	`LINE,8,2GRID,,2,7`	
34	`LINE,9,2GRID,,4,9`	
35	`LINE,10,2GRID,,5,10`	
36	`PATCH,1,EDGE,,2/9/5/8`	define patches
37	`PATCH,2,EDGE,,1/8/4/7`	
38	`PATCH,3,EDGE,,3/10/6/9`	

Line	PCL or PATRAN Command	Comment
39	HPAT,1,ARC,	define hyperpatches
	0/0/0/0/0/1/‘staveangle‘/‘slotangle‘,P1	
40	HPAT,2T‘nstave‘,ROTATE,	
	0/0/0/0/0/1/‘360.0/nstave‘,1	
41	HPAT,‘nstave+1‘,ARC,	
	0/0/0/0/0/1/‘staveangle‘/‘slotangle‘,P2	
42	HPAT,‘nstave+2‘T‘2*nstave‘,ROTATE,	
	0/0/0/0/0/1/‘360.0/nstave‘,‘nstave+1‘	
43	HPAT,‘2*nstave+1‘.ARC,	
	0/0/0/0/0/1/‘staveangle‘/‘slotangle‘,P3	
44	HPAT,‘2*nstave+2‘T‘3*nstave‘,ROTATE,	
	0/0/0/0/0/1/‘360.0/nstave‘,‘2*nstave+1‘	
45	HPAT,‘3.0*nstave+1‘,ARC,	
	0/0/0/0/0/1/‘2.0*slotangle‘/‘-slotangle‘,P2	
46	HPAT,‘2+3*nstave‘T‘4*nstave‘,ROTATE,	
	0/0/0/0/0/1/‘360.0/nstave‘,‘3*nstave+1‘	
47	HPAT,‘1+4*nstave‘,ARC,	
	0/0/0/0/0/1/‘2.0*slotangle‘/‘-slotangle‘,P3	
48	HPAT,‘2+4*nstave‘T‘5*nstave‘,ROTATE,	
	0/0/0/0/0/1/‘360.0/nstave‘,‘1+4*nstave‘	
49	MESH,H1T#,HEX/8,ISO,0.01,-1	create finite elements
50	EQUIVALENCE	equivalence all
51	N	duplicate nodes
52	2	
53	1	
54	Y	
55	7	
56	1	
57	1	
58	RENUMBER	renumber everything
59	3	
60	1	
61	4	
62	NEUTRAL	create the Neutral file
63	1	
64	1	
65	EIGEN ANALYSIS 8 SLOTTED SHELL	title
66	Y	
67	Y	
68	2	All done

Lines 36-38 create patches (surfaces) from the lines and arcs. The patches are swept about the Z axis to form hyperpatches (volumes) in Lines 39-48. Line 39 also illustrates that a PATRAN command line can be continued onto the following line if the last character is a comma.

The finite element mesh is created with the single `MESH` command on Line 49. Hexahedral elements with 8 nodes are selected, with side length of 0.01m, and containing material with mid = 1, as defined in Line 3. A more general approach would be to make the element side length a fraction of some shell dimension.

In Line 50, the `EQUIVALENCE` command equivalences nodes whose separation is less than the tolerance set in Line 2. This is an important step, it attaches all the elements of the model together into a single piece of material. Note that if the tolerance were set larger than the slot width, the slots would be fused together, which would not be desirable. Therefore, when writing a more robust version of this session file, the tolerance should be set to be less than some fraction of the slot width.

The `EQUIVALENCE` operation may delete some nodes, which will disrupt the node numbering sequence of the remaining nodes. The `RENUMBER` command on Line 58 is a house-cleaning operation that sequentially renumbers the nodes[6].

At this stage it would be appropriate to set the boundary conditions, however in this example the modes of a completely unconstrained shell are desired, so no boundary conditions are needed. Since nothing prevents the shell from undergoing rigid body translations or rotations MAVART3D may find the 6 rigid body modes[7] unless the eigenvalue search starting frequency is set suitably high, e.g., higher than the lowest vibrational mode. This may require several trials, since the lowest frequency is not known a priori. Thus, the first real mode can be expected to be number 7.

The PATRAN Neutral file containing all the model data is written out in Lines 62-67, and after this the model is ready for PATMAV translation.

In the consecutive mode, at this point, the PATRAN session can be terminated, followed by an invocation of PATMAV. PATMAV will prompt for all data required to perform the translation. To produce the results presented in Section 4.1, the user supplied inputs to PATMAV were all default values (invoked by carriage returns) with the exception of the following: (1) the selection of EIGE analysis, (2) the selection of the search node (node 1, which is at the end of the shell, was used), (3) search degree of freedom (Z), and (4) the frequency range for the search (1200-5000 Hz).

In the concurrent mode of operation, PATMAV translation can be invoked with the `INTERFACE, TO MAVART3D` commands in PATRAN. As explained in Section 3, the DCL procedures in Appendix A will then be executed. They, in turn, will run PATMAV, and prompt the user for input. When the MAVART3D analysis is complete, as indicated by a

[6]Node and element numbering can have an impact on the cpu time of finite element solvers, so PATRAN provides the `OPTIMIZE` command, not used here, which allows users to renumber entities according to various optimization schemes.

[7]This results in MAVART3D terminating with an error message that a negative eigenvalue has been found.

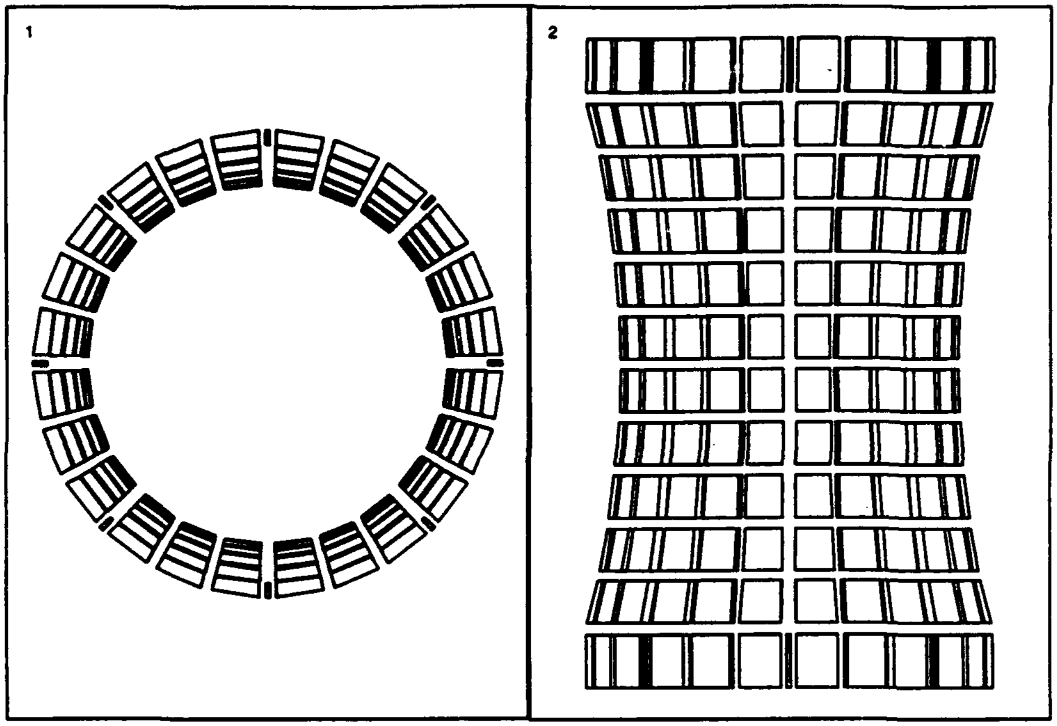

Figure 4: *Finite element model of barrel stave shell*

message from the batch processor, the PATRAN commands `INTERFACE, FROM MAVART3D`, can be selected and to run MAVPAT under the control of the DCL procedure MAVPAT.COM. The user will be prompted for MAVPAT input, and when MAVPAT file translation is complete, control is returned to PATRAN. The `RESULTS` command can be given, and then the translated files can be displayed.

A drawing of the model created by the session of Table 2 is shown in Fig. 4. The PATRAN command: `SET, SHRINK, .1`, has been used to draw the elements 10% smaller than their true size, to delineate them better. As a quick check on the fidelity of the model, the mass of the model was computed using a density of $2700kg/m^3$ and the PATRAN command: `SHOW, MASSPROP, 2700.0` . The result was 220.2 gms, which agrees well with the measured mass (220.19 gms) of the actual shell from which the dimensions for the model were taken. The model includes the full shell, but for many types of finite element analysis only a fraction of the shell (e.g. as little as 1/(2 `nstave`) of the total) would need to be modelled. The full shell has to be modelled if all vibrational modes including torsional vibrations are to be studied.

The advantage of using PCL is best seen by considering how easy it is to change the model, e.g., to change the number of staves. This changes the number of hyperpatches required, and leads to a completely different finite element mesh. Changing the number of staves can be done simply by changing the single variable `nstave` on Line 7 of Table 2

and running the modified session file through PATRAN. The PCL routine creates the required number of hyperpatches, and automatically fills them with elements. The entire change can be done in a few minutes. This is in sharp contrast to a model built by strictly menu driven grid generation software, such as LAPCAD[9], where a change such as this would require the manual re-entry of the entire model, a process that could take many hours, depending on the size and complexity of the model.

It is possible to allow the parametric design process to be controlled interactively, by using PCL commands to query the user for the design parameters, such as the number of staves. This technique would be useful for creating a "turnkey" design environment for a particular sonar transducer, which could be used by someone with only modest experience with PATRAN and the finite element method.

In this example, the model geometry was defined using just a handful of PCL code. At some stages in building a more complex model, it may not be so easy to anticipate the values certain PATRAN parameters may assume, e.g., the index of a particular node, or the number of elements in a particular hyperpatch, and yet those parameters may be useful for building the rest of the model. It may be convenient to treat such cases by using PCL commands to interrogate the PATRAN database, and read the required parameters, rather than try to define them directly using PCL commands as has been done above. For example, the hyperpatch indexing in Lines 39-48 of Table 2 could have been somewhat simplified by using PCL database commands to determine the current highest numbered hyperpatch.

4.1 Display of Results of Barrel Stave Modal Analysis

In this section, some of the results of the MAVART3D modal analysis of the barrel stave shell model are presented. Hidden line images of the 4 lowest frequency mode shapes (modes 8,10,11, and 13), are shown in Fig. 5. Note that the mode with lowest frequency is not the axially symmetric breathing mode used in the normal operation of the barrel stave projector, but rather a circumferential ovalization mode. When displayed by PATRAN on a suitable workstation, images like these can be viewed from any direction, and animated.

To make the drawings in Fig. 5, MAVPAT was used to translate the MAVART3D output plot files to PATRAN results file format. Then the following sequence of commands was input to PATRAN:

PATRAN PROMPT	USER RESPONSE
`MODE?`	1 (RESULTS)
`RESULTS TYPE?`	2 (EXTERNAL DATA)
`RESULTS?`	1 (DEFORMED SHAPE)
`INPUT NAME OF DISPLACEMENT FILE:`	`DISPLACEMENT.DAT;nn`

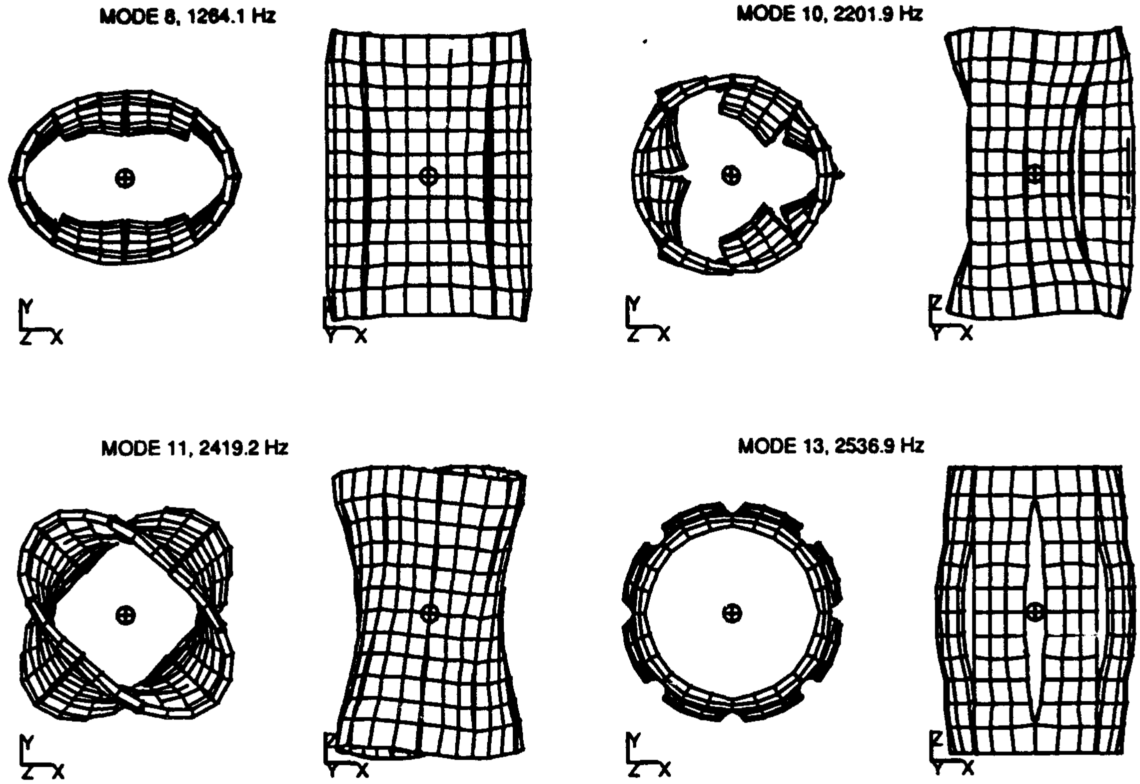

Figure 5: *Mode shapes of lowest 4 modes of barrel stave shell as predicted by MAVART3D.*

The version number "nn" in the last of the preceding commands refers to one of the DISPLACEMENT.DAT files of which there is one for each eigenfrequency. The preceding command sequence was repeated for each of the mode shapes shown in Fig. 5. The frequencies of the predicted modes shown in Fig. 5 will be checked by performing experimental modal analysis on actual shells, and this verification will be reported elsewhere.

In addition to the 6 rigid body modes, with zero frequency, there are other missing modes (7, 9, 12) with respect to those shown in Fig. 5. These are probably degenerate modes. For example, additional MAVART3D EIGE analyses with different search nodes and search degrees of freedom, established that modes 7 and 8 have the same eigenfrequency, but correspond to different eigenvectors, i.e., modes 7 and 8 differ in shape, but only by a rotation about the Z axis.

5 Summary and Conclusions

MAVPAT Version 1.0 completes the set of software tools required for effective use of the finite element code MAVART3D Version 1.0. It is now possible, using a graphics terminal or workstation and PATRAN, PATMAV, MAVART3D, and MAVPAT, to create and analyze fully three-dimensional finite element models of piezoelectric transducers, loaded with static forces, undergoing free oscillations, or being driven by complex valued charge, voltage, temperature, force, or displacement excitations in vacuum. All MAVART3D elements, material properties, and boundary conditions are supported. The translation of data files, invocation of MAVART3D, and the display of results is fully integrated within the PATRAN system. The PATRAN-generated colour images of MAVART3D results can be made easy to interpret, and are esthetically appealing. The complete software system, consisting of PATRAN, PATMAV, MAVART3D, and MAVPAT, is a major advance in transducer modelling capability that should make a substantial contribution to the productivity of those who use this software.

From the user's point of view, the operation of MAVPAT is simple, so that most of this document has concerned itself with system configuration and with the introduction of the concept of parametric modelling. This technique consists of describing a finite element model by mathematical relationships dependent upon a set of essential parameters, from which the model generation software can build a complete finite element mesh automatically. The parameters in the example presented could easily be modified to build a series of models that would be valuable for optimizing a barrel stave projector design. This technique promises to have a major impact on the way finite element analysis of transducers is done at DREA in the future.

5.1 Further Developments of MAVPAT

Because PATRAN can create and display results from two dimensional models, it would be desirable to add support for the axisymmetric MAVART analysis to both PATMAV and MAVPAT. MAVART3D Version 2.0 is expected to be delivered in 1993. It will have the capability to model acoustic radiation using the boundary element method. It will be desirable to make modifications to both PATMAV and MAVPAT to support radiation modelling.

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Appendix A: Command Procedures

The command procedures PATMAV.COM and MAVPAT.COM, (and the subprograms BATCH.COM and M3D.COM) that are invoked by selecting the PATRAN command **INTERFACE**, followed by **TO MAVART3D**, are as follows:

```
$! Command procedure 'patmav.com'
$! This procedure invokes PATRAN to MAVART3D translation from within
$! PATRAN, and submits a batch job to run MAVART3D in a queue. The
$! next line identifies the current user directory and defines a
$! symbol for it that can be passed to the following commands.
$ defdir==f$environment("default")
$ run dreapacs:[mavart]patmav.exe
$ @dreapacs:[mavart]batch dreapacs:[mavart]m3d 'defdir'
$ exit
$!*********************************************************************
$! Command procedure 'batch.com', usage:  @ batch p1 p2
$! This procedure submits the command file specified by 'p1'
$! to a batch queue. The parameter 'p2' is the default directory to
$! be used by command file 'p1' for getting data and writing results.
$ submit/queue=sys$big_batch/notify/noprinter/parameters='p2' 'p1'
$ exit
$!*********************************************************************
$! Command procedure 'm3d.com', usage:  @ m3d p1
$! The parameter p1 is the default directory. This procedure runs
$! mavart3d in the directory as set below. This procedure is invoked
$! with the command procedure 'batch.com'.
$ set default 'p1'
$ run dreapacs:[mavart.mavart3d]mavart3d.exe
VAX
1
x
mav.dat
$ exit
$!*********************************************************************
$! Command procedure mavpat.com, usage: @ mavpat.com
$ dir/size/since=today *plt*.dat
$! The following line establishes that the input for the following
$! run command will be the original input stream, usually the terminal.
$ define/user_mode sys$input sys$command
$ run dreapacs:[mavart]mavpat.exe
$ exit
```

Appendix B: MAVPAT Results File Contents

Table B1: *Format for nodal displacements file DISPLACEMENT.DAT*

Record #	Contents	Format
1	Title (from MAVART3D Data Card 1)	(80A1)
2	NN, MAXN, DMAX, NMAX, 3	(2I9, E15.6, 2I9)
3	Date and Time	(80A1)
4	"Displacements at nodes"	(80A1)
5 to NN+4	ID, (DATA(J), J = 1, 3)	(I8, (3E13.7))

NN is the number of nodes, MAXN is the highest node identifier, DMAX is the maximum absolute displacement, NMAX is the node where the max displacement occurs, DATA(j), (j = 1, 3) are X,Y,Z displacements of the nodes of all elements. For EIGE analysis, the mode number and resonance frequency also appear in Record 4. For DRIV analysis, the phase (radians) at which the displacements have been calculated appears in Record 4 instead.

Table B2: *Format for nodal voltage file VOLTAGE.DAT*

Record #	Contents	Format
1	Title	(80A1)
2	NN, MAXN, DMAX, NMAX, 1	(2I9, E15.6, 2I9)
3	Date and Time	(80A1)
4	"Nodal Voltages"	(80A1)
5 to NN+4	ID, DATA	(I8, (5E13.7))

NN is the number of nodes, MAXN is the highest node identifier, DMAX is the maximum absolute voltage, NMAX is the node where the max voltage occurs, DATA is the voltage at PIEZO nodes. For EIGE analysis, the mode number and resonance frequency also appear in Record 4. For DRIV analysis, the phase (radians) at which the voltages have been calculated appears in Record 4 instead.

Table B3: *Format for nodal strain file NSTRAIN.DAT*

Record #	Contents	Format
1	Title	(80A1)
2	NN, MAXN, 0, 0, 9	(2I9, E15.6, 2I9)
3	Date and Time	(80A1)
4	"Strain at corner nodes"	(80A1)
5 to NN+4	ID, (DATA(J), J = 1, 9)	(I8, (3E13.7))

NN is the number of nodes, MAXN is the highest node identifier, DATA(j), (j = 1, 9) are the 6 components of strain, followed by the 3 components of electric field at the corner nodes of all elements. The electric field values will be non-zero only at PIEZO nodes.

Table B4: *Format for nodal stress file NSTRESS.DAT*

Record #	Contents	Format
1	Title	(80A1)
2	NN, MAXN, 0, 0, 9	(2I9, E15.6, 2I9)
3	Date and Time	(80A1)
4	"Stress at corner nodes"	(80A1)
5 to NN+4	ID, (DATA(J), J = 1, 9)	(I8, (3E13.7))

NN is the number of nodes, MAXN is the highest node identifier, DATA(j), (j = 1, 9) are the 6 components of stress, followed by the 3 components of electric displacement at the corner nodes of all elements. The electric displacement values will be non-zero only at PIEZO nodes.

Table B5: *Format for element strain file ESTRAIN.DAT*

Record #	Contents	Format
1	Title	(80A1)
2	9	(I5)
3	Subtitle1	(80A1)
4	Subtitle2	(80A1)
5 to NN+4	ID, NSHAPE, (DATA(J), J=1, 9)	(2I8,/,(6E13.7))

NN is the number of elements, ID is the element identifier, NSHAPE is the element shape code (BAR = 2, TRIANGLE = 3, QUADRILATERAL = 4, TETRAHEDRON = 5, WEDGE = 7, HEX = 8), DATA(j), (j = 1, 9) are the 6 components of strain, followed by the 3 components of electric field at the corner nodes of all elements. The electric field values will be non-zero only at PIEZO nodes.

Table B6: *Format for element stress file ESTRESS.DAT*

Record #	Contents	Format
1	Title	(80A1)
2	9	(I5)
3	Subtitle1	(80A1)
4	Subtitle2	(80A1)
5 to NN+4	ID, NSHAPE, (DATA(J), J=1, 9)	(2I8,/,(6E13.7))

NN is the number of elements, ID is the element identifier, NSHAPE is the element shape code (BAR = 2, TRIANGLE = 3, QUADRILATERAL = 4, TETRAHEDRON = 5, WEDGE = 7, HEX = 8), DATA(j), (j = 1, 9) are the 6 components of stress, followed by the 3 components of electric displacement at the corner nodes of all elements. The electric displacement values will be non-zero only at PIEZO nodes.

Table B7: *Format for frequency sweep results file ADMITTANCE.DAT*

Record #	Contents	Format
1	"XDATA", Title, "frequencies (Hz)"	(A5,2A40)
2 TO 1 + N	FREQ	(*)
2 + N	"END"	(A3)
3 + N	"YDATA", Title, "conductance (mho)"	(A5,2A40)
4 + N TO 3 + 2 * N	DATA	(*)
4 + 2 * N	"END"	(A3)
5 + 2 * N	"YDATA", Title, "susceptance (mho)"	(A5,2A40)
6 + 2 * N TO 5 + 3 * N	DATA	(*)
6 + 3 * N	"END"	(A3)
7 + 3 * N	"YDATA", Title, "resistance (ohm)"	(A5,2A40)
8 + 3 * N TO 7 + 4 * N	DATA	(*)
8 + 4 * N	"END"	(A3)
9 + 4 * N	"YDATA", Title, "reactance (ohm)"	(A5,2A40)
10 + 4 * N TO 9 + 5 * N	DATA	(*)
10 + 5 * N	"END"	(A3)
11 + 5 * N	"YDATA", Title, "voltage (volts)"	(A5,2A40)
12 + 5 * N TO 11 + 6 * N	DATA	(*)
12 + 6 * N	"END"	(A3)
13 + 6 * N	"YDATA", Title, "X displacement (m) "	(A5,2A40)
14 + 6 * N TO 13 + 7 * N	DATA	(*)
14 + 7 * N	"END"	(A3)
15 + 7 * N	"YDATA", Title, "Y displacement (m)"	(A5,2A40)
16 + 7 * N TO 15 + 8 * N	DATA	(*)
16 + 8 * N	"END"	(A3)
17 + 8 * N	"YDATA", Title, "Z displacement (m)"	(A5,2A40)
18 + 8 * N TO 17 + 9 * N	DATA	(*)
18 + 9 * N	"END"	(A3)

N is the number of frequencies at which MAVART3D has computed results. FREQ is the frequency of the analysis. DATA is the corresponding analysis result. The analysis type must be DRIV in order for the conductance to be non-zero. Also resistance and reactance are only included in ADMITTANCE.DAT when the analysis type is DRIV. Voltage, and X, Y, and Z displacements are evaluated at node NSEL, which is the node selected (using PATMAV) for results evaluation in MAVART3D.

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This communication describes how to use the computer program MAVPAT, Version 1.0, developed at Defence Research Establishment Atlantic (DREA) to translate MAVART3D analysis results files to a form compatible with the finite element modelling program PATRAN. MAVART3D is a computer program used for finite element analysis of piezoelectric sonar transducers. Once read by PATRAN, the translated MAVART3D analysis results can be displayed graphically, and superimposed on images of the finite element model. This communication shows how to configure the PATRAN software so that finite element model generation, MAVART3D analysis, data translation, and display of results can all be done within the PATRAN environment. The integrated operation of PATRAN, PATMAV, MAVART3D, and MAVPAT is illustrated with the worked example of the modal analysis of the shell of a barrel stave projector. The example also shows how PATRAN Command Language can be used in the parametric design of a sonar transducer.

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